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A review of energy use and energy efficiency technologies for the textile industry

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ABSTRACT

The textile industry is a complicated manufacturing industry because it is a fragmented and heterogeneous sector dominated by small and medium enterprises (SMEs). There are various energy-efficiency opportunities that exist in every textile plant. However, even cost-effective options often are not implemented in textile plants mostly because of limited information on how to implement energy-efficiency measures. Know-how on energy-efficiency technologies and practices should, therefore, be prepared and disseminated to textile plants. This paper provides information on the energy use and energy-efficiency technologies and measures applicable to the textile industry. The paper includes case studies from textile plants around the world and includes energy savings and cost information when available. A total of 184 energy efficiency measures applicable to the textile industry are introduced in this paper. Also, the paper gives a brief overview of the textile industry around the world. An analysis of the type and the share of energy used in different textile processes is also included in the paper. Subsequently, energy-efficiency improvement opportunities available within some of the major textile sub-sectors are given with a brief explanation of each measure. This paper shows that a large number of energy efficiency measures exist for the textile industry and most of them have a low simple payback period.

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1. Introduction

The textile industry is one of the most complicated manufacturing industries because it is a fragmented and heterogeneous sector dominated by small and medium enterprises (SMEs). Characterizing the textile manufacturing industry is complex because of the wide variety of substrates, processes, machinery and components used, and finishing steps undertaken. Different types of fibers or yarns, methods of fabric production, and finishing processes (preparation, printing, dyeing, chemical/mechanical finishing, and coating), all interrelate in producing a finished fabric.

Energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy-efficiency should be a primary concern for textile plants. There are various energy-efficiency opportunities that exist in every textile plant, many of which are cost-effective. However, even cost-effective options are not often implemented in textile plants mostly because of limited information on how to implement such energy-efficiency measures, especially given the fact that a majority of textile plants are categorized as SMEs and hence they have limited resources to acquire this information. Know-how on energy-efficiency technologies and practices should, therefore, be prepared and disseminated to textile plants. An extensive literature review was conducted in this study to collect information on the energy use in and energy efficiency measures/technologies for the textile industry. More than 140 references were reviewed [1–142].

Although the textile sector has significant energy consumption, there are not many scientific papers published to address the energy issues in the textile industry. Ozturk [94] reports on energy use and energy cost in the Turkish textile industry based on conducted surveys. Martinez [89] analyzes the development of energy-efficiency measures in the German and Colombian textile industries, using three alternative indicators to measure energy-efficiency performance between 1998 and 2005. A recent study in Taiwan summarizes the energy savings implemented by 303 firms in Taiwan's textile industry from the on-line energy Declaration System in 2008. It was found that the total implemented energy savings amounted to 1929 terajoules (TJ) [76]. Palanichamy and Sundar Babu [95] studied energy use in the Indian textile industry and present the energy-efficiency potential availability, as well as suggesting some energy policies suitable in the Indian context to achieve the estimated energy-savings potential.

In addition to these research papers, there are also several reports and guides for energy-efficiency in the textile industry. Carbon Trust's report [14] serves as a guide for the textile dyeing and finishing industry. The Hasanbeigi [72] report is a comprehensive collection of around 190 sector-specific and cross-cutting energy-efficiency measures and technologies for the textile industry. The Canadian Industry Program for Energy Conservation (CIPEC) has also published a report on benchmarking and best practices in Canadian textile wet-processing [21]. The Energy Conservation Center of Japan also published a report on energy-efficiency technologies for the textile industry [41].

The work presented in this paper is a unique study for the textile industry, as it provides a clear image of the energy use in the textile industry and presents a long list of 184 energy efficiency measures for the textile industry, from which around 114 measures are textile sector-specific measures and the other 70 measures are cross-cutting measures found in all textile sub-sectors. This paper is based on Hasanbeigi [72], which includes around 190 sector-specific and cross-cutting energy-efficiency measures and technologies for the textile industry. For a detailed explanation of each energy efficiency technology/measure given in this paper, we refer the readers to this report [72].

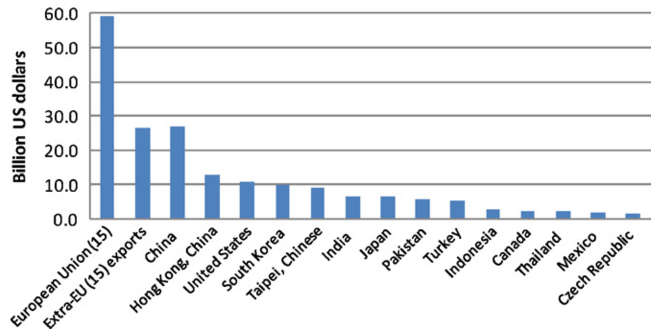

Fig. 1. Leading exporters of textiles in 2003 [140].

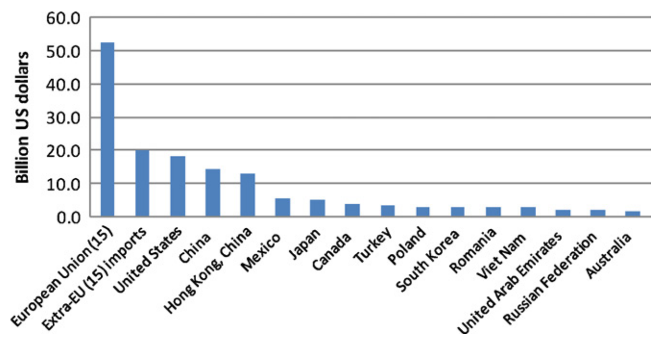

Fig. 2. Leading importers of textiles in 2003 [140].

2. Overview of the textile industry

The textile industry has played an important role in the development of human civilization over several millennia. Coal, iron and steel, and cotton were the principal materials upon which the industrial revolution was based. Technological developments from the second part of the eighteenth century onwards led to an exponential growth of cotton output, first starting in the U.K., and later spreading to other European countries. The production of synthetic fibers that started at the beginning of the twentieth century also grew exponentially [106].

The textile industry is traditionally regarded as a labor-intensive industry developed on the basis of an abundant labor supply. The number of persons employed in the textile and clothing industry was around 2.45 million in the European Union (EU) in 2006 [68], around 500,000 in the U.S. in 2008 [133], and about 8 million in China in 2005 [101].

China is the world's largest textile exporter with 40% of world textile and clothing exports [69]. The textile industry is the largest manufacturing industry in China with about 32,400 enterprises above designated size[1] in 2009. The gross industrial output value of the textile enterprises above designated size was 2291 billion Yuan in 2009 (US$336.9 billion) [142]. This does not include the clothing industry. In 2008, the total export value of China's textile industry was US $65.4 billion, an increase of 16.6% compared to 2007. With the rising living standard of the Chinese people, local demand for high quality textiles and apparel goods continues to increase [25]. China is also the largest importer of textile machinery and Germany is the largest exporter of textile machinery [111]. Figs. 1 and 2 show the leading exporters and importers of textiles in 2003 with the amount of exports and imports in billion U.S. dollars. It should be noted that the graphs are just for textiles and do not

[1] Industrial enterprises above designated size are those with annual revenue from principal business over 5 million Yuan (around US$581,000 using the exchange rate of 6.8 Yuan/US$).

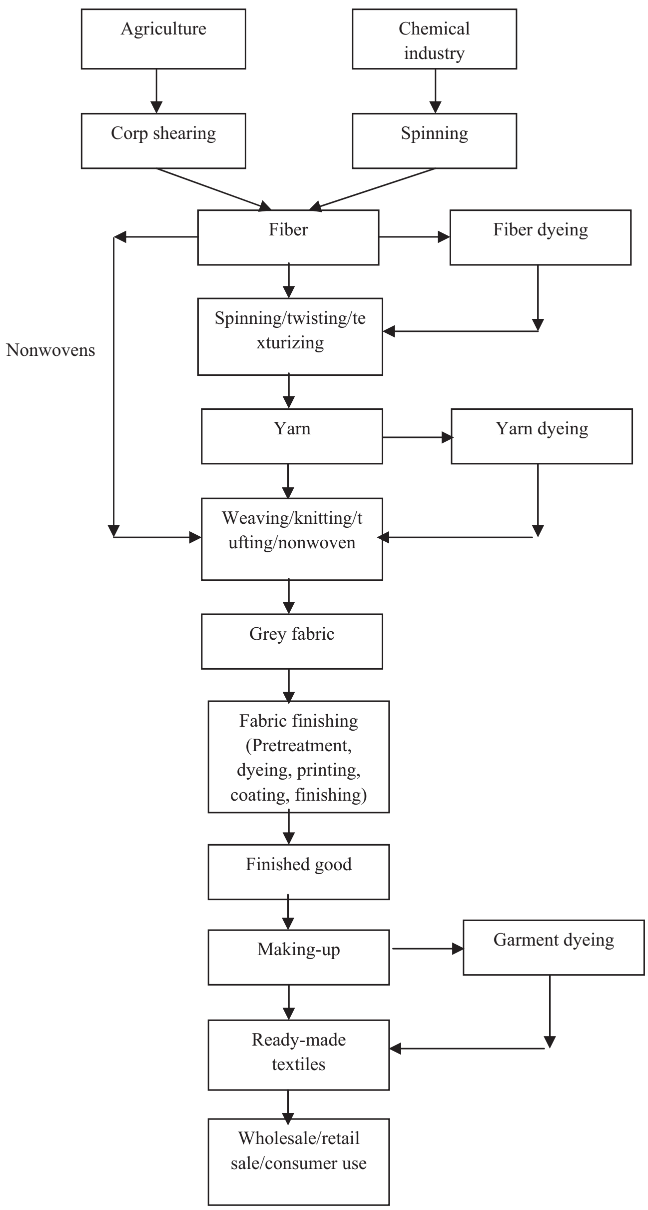

Fig. 3. The textile chain [106].

include clothing. As can be seen in the figures, the EU, China, and the U.S. are the three largest textile importers and exporters.

The EU textile and clothing sector represents 29% of the world textile and clothing exports, not including trade between EU Member countries, which places the EU second after China [69]. In 2006 there were 220,000 textile companies in EU employing 2.5 million people and generated a turnover of €190 billion. The textile and clothing sector accounts for around 3% of total manufacturing value added in Europe [67].

3. Textile processes

Fig. 3 is a generalized flow diagram depicting the various textile processes that are involved in converting raw materials in to a finished product. All of these processes do not occur at a single facility, although there are some vertically integrated plants that have several steps of the process all in one plant. There are also several niche areas and specialized products that have developed in the textile industry which may entail the use of special processing steps that are not shown in Fig. 3.

Due to the variety of the processes involved in the textile industry, there are too many processes to be explained within the space constraints of this paper. Thus, brief descriptions only for the major textile processes for which the energy-efficiency measures are given here can be found in [72]. The major textile processes that are discussed in the paper are presented below. These are the most important and account for the largest share of textile industry energy use.

- Spun yarn spinning
- Weaving
- Wet-processing (preparation, dyeing, printing, and finishing)
- Man-made fiber production

4. Energy use in the textile industry

The textile industry, in general, is not considered an energy-intensive industry. However, the textile industry comprises a large number of plants which together consume a significant amount of energy. The share of total manufacturing energy consumed by the textile industry in a particular country depends upon the structure of the manufacturing sector in that country. For example, the textile industry accounts for about 4% of the final energy use in manufacturing in China [88], while this share is less than 2% in the U.S. [122].

The share of the total product cost expended on energy in the textile industry also varies by country. Table 1 shows the general shares of cost factors for 20 Tex[2] combed cotton yarn in several countries. Energy cost is often the third or fourth highest share of total product cost.

The textile industry uses large quantities of both electricity and fuels. The share of electricity and fuels within the total final energy use of any one country's textile sector depends on the structure of the textile industry in that country. For example, in spun yarn spinning, electricity is the dominant energy source, whereas in wet-processing the major energy source is fuels. Manufacturing census data from 2002 in the U.S. shows that 61% of the final energy used in the U.S. textile industry was fuel energy and 39% was electricity. The U.S. textile industry is also ranked the 5th largest steam consumer among 16 major industrial sectors studied in the U.S. The same study showed that around 36% of the energy input to the textile industry is lost onsite (e.g. in boilers, motor systems, distribution, etc.) [120].

4.1. Breakdown of energy use by end-use

In a textile plant, energy is used in different end-uses for different purposes. Fig. 4 shows the breakdown of final energy use by end use in the U.S. textile industry [120]. Although the percentages shown in the graph can vary from one country to another, this figure gives an indication of final energy end-use in the textile industry.[3] *However, it should be noted that it is more likely that the textile industry in the U.S. does not include as many labor-intensive processes (e.g. spinning and weaving) as it does in some developing countries like China and India where the cost of labor is lower.* As is shown in the Fig. 4, in the U.S. textile industry steam and

[2] The Tex is one of the several systems to measure the yarn count (fineness). The Tex count represents the weight in grams per 1 kilometer (1000 m) of yarn. For example, a yarn numbered 20 Tex weighs 20 g per kilometer. The Tex number increases with the size of the yarn.

[3] The reason why this breakdown is presented for the U.S. is that we could only find the data for such a breakdown at the aggregate country level for the U.S.

Table 1
Share of manufacturing cost factors for 20 tex combed cotton yarn in several countries in 2003 (Koç and Kaplan [85]).

Cost factors	Brazil	China	India	Italy	Korea	Turkey	USA
Raw material	50%	61%	51%	40%	53%	49%	44%
Waste	7%	11%	7%	6%	8%	8%	6%
Labor	2%	2%	2%	24%	8%	4%	19%
Energy	5%	8%	12%	10%	6%	9%	6%
Auxiliary material	4%	4%	5%	3%	4%	4%	4%
Capital	32%	14%	23%	17%	21%	26%	21%
Total	100%	100%	100%	100%	100%	100%	100%

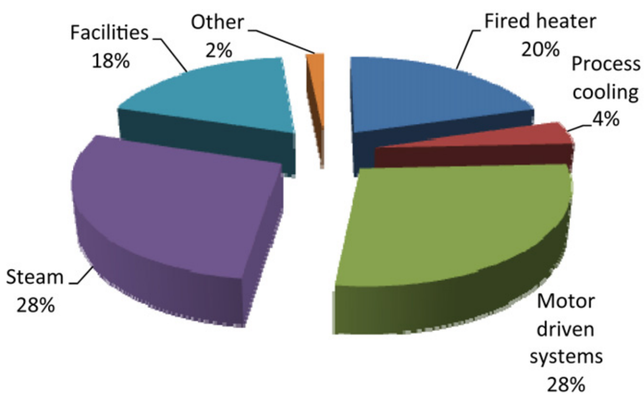

Fig. 4. Final energy end-use in the U.S. textile industry [120].

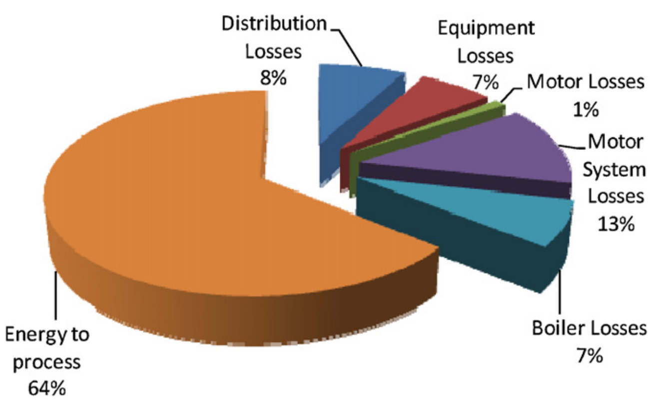

Fig. 5. Onsite energy loss profile for the U.S. textile industry [120].

motor-driven systems (pumps, fans, compressed air, material handling, material processing, etc.) have the highest share of end-use energy use and each one accounts for 28% of total final energy use in the U.S. textile industry.

As indicated, there are significant losses of energy within textile plants. Fig. 5 shows the onsite energy loss profile for the U.S. textile industry [120]. Around 36% of the energy input to the U.S. textile industry is lost onsite. Motor driven systems have the highest share of onsite energy waste (13%) followed by distribution[4] and boiler losses (8% and 7% respectively). The share of losses could vary for the textile industry in other countries depending on the structure of the industry in those countries. However, Fig. 5 gives an illustration of where the losses happen and the relative importance of each loss in the U.S. textile industry.

As shown above, motor driven systems are one of the major sources of waste of end-use energy waster in the textile industry. Fig. 6 shows the breakdown of energy used by motor systems in different processes in the U.S. textile industry. As can be seen, material

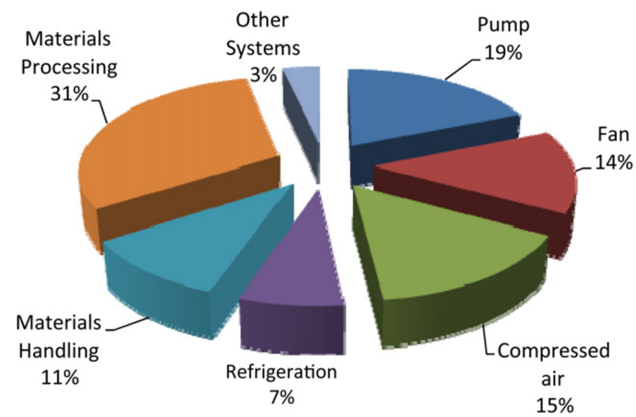

Fig. 6. Breakdown of motor systems energy use in the U.S. textile industry [120].

processing is responsible for the highest share of energy used by motor driven systems (31%) followed by pumps, compressed air, and fan systems (19%, 15%, and 14% respectively). Again, these percentages in other countries will highly depend on the structure of the textile industry in those countries. For example, if the weaving industry in a country has a significantly higher share of air-jet weaving machines (which consume high amounts of compressed air) than in the U.S., the share of total motor driven system energy consumed by compressed air energy systems would probably be higher than indicated in Fig. 6.

4.2. Breakdown of energy use by textile processes

4.2.1. Energy use in the spinning process

Electricity is the major type of energy used in spinning plants, especially in cotton spinning systems. If the spinning plant just produces raw yarn in a cotton spinning system, and does not dye or fix the produced yarn, the fuel may just be used to provide steam for the humidification system in the cold seasons for preheating the fibers before spinning them together. Therefore, the fuel used by a cotton spinning plant highly depends on the geographical location and climate in the area where the plant is located. Fig. 7 shows the breakdown of final energy use in a sample spinning plant that has both ring and open-end spinning machines.

Koç and Kaplan [85] calculated the energy consumption for spinning different types and counts of yarn and the results are shown in Table 2. For all types of fibers, finer yarn spinning consumes more energy. Yarns used for weaving involve more twisting than yarns used for knitting. Also, production speed is low for weaving yarn compared to that of knitting yarn. As a result, with the same yarn count, more energy is consumed for weaving yarn. Also, for the same yarn count, the energy consumption for combed yarn is higher because of the additional production step (combing).

4.2.2. Energy use in wet-processing

Wet-processing is the major energy consumer in the textile industry because it uses a high amount of thermal energy in the

[4] Energy distribution losses are for both inside and outside of the plant boundary.

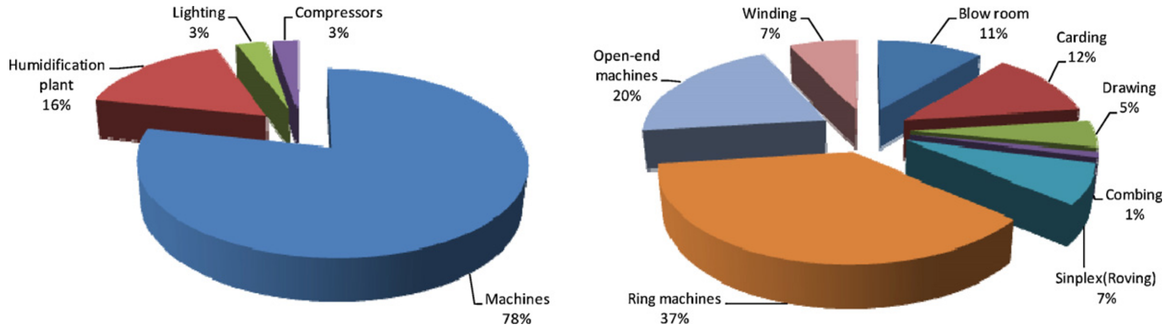

Fig. 7. Breakdown of the final energy use in a spinning plant that has both ring and open-end spinning machines [120]. *Note*: The graph on the right shows the breakdown of the energy use by the category "Machines" that is shown in the graph on the left.

Table 2
Typical specific energy consumption (kWh/100 kg) for yarns with different yarn counts and final use (weaving vs. knitting) [86].

Yarn count (Tex)	Combed yarn		Carded yarn	
	Knitting	Weaving	Knitting	Weaving
37	138	163	134	162
33	158	188	154	186
30	179	212	173	209
25	219	260	211	255
20	306	364	296	357
17	389	462	374	453
15	442	525	423	512
12	552	681	552	672

Table 3
Typical energy requirements for textile wet-processes, by product form, machine type and process [14].

Product form/machine type	Process	Energy requirement (GJ/ton output)
Desize unit	Desizing	1.0–3.5
Kier	Scouring/bleaching	6.0–7.5
J-box	Scouring	6.5–10.0
Open width range	Scouring/bleaching	3.0–7.0
Low energy steam purge	Scouring/bleaching	1.5–5.0
Jig/winch	Scouring	5.0–7.0
Jig/winch	Bleaching	3.0–6.5
Jig	Dyeing	1.5–7.0
Winch	Dyeing	6.0–17.0
Jet	Dyeing	3.5–16.0
Beam	Dyeing	7.5–12.5
Pad/batch	Dyeing	1.5–4.5
Continuous/thermosol	Dyeing	7.0–20.0
Rotary Screen	Printing	2.5–8.5
Steam cylinders	Drying	2.5–4.5
Stenter	Drying	2.5–7.5
Stenter	Heat setting	4.0–9.0
Package/yarn	Preparation/dyeing (cotton)	5.0–18.0
Package/yarn	Preparation/dyeing (polyester)	9.0–12.5
Continuous hank	Scouring	3.0–5.0
Hank	Dyeing	10.0–16.0
Hank	Drying	4.5–6.5

forms of both steam and heat. The energy used in wet-processing depends on various factors such as the form of the product being processed (fiber, yarn, fabric, cloth), the machine type, the specific process type, the state of the final product, etc. Table 3 shows the typical energy requirements for textile wet-processing by the product form, machine type, and process. Table 4 gives a breakdown of thermal energy use in a dyeing plant (with all dyeing processes included). Although the values in this table are the average values for dyeing plants in Japan, it provides a good example of where the thermal energy is used, allowing the discovery of opportunities for energy-efficiency improvement. It can be seen that a significant share of thermal energy in a dyeing plant is lost through wastewater loss, heat released from equipment, exhaust gas loss, idling, evaporation from liquid surfaces, un-recovered condensate, loss during condensate recovery, and during product drying (e.g. by over-drying). These losses can be reduced by different energy-efficiency measures explained in the next section of this paper.

4.2.3. *Breakdown of energy use in composite textile plants (spinning-weaving-wet processing)*

A composite textile plant is a plant that has spinning, weaving/knitting, and wet-processing (preparation, dyeing/printing, finishing) all on the same site. Fig. 8 shows the breakdown of the typical electricity and thermal energy use in a composite textile plant [105]. As can be seen, spinning consumes the greatest share of electricity (41%) followed by weaving (weaving preparation and weaving) (18%). Wet-processing preparation (desizing, bleaching, etc.) and finishing together consume the greatest share of thermal

Table 4
Breakdown of thermal energy use in a dyeing plant (average in Japan) [40].

Item	Share of total thermal energy use
Product heating	16.6%
Product drying	17.2%
Waste water loss	24.9%
Heat released from equipment	12.3%
Exhaust gas loss	9.3%
Idling	3.7%
Evaporation from liquid surfaces	4.7%
Un-recovered condensate	4.1%
Loss during condensate recovery	0.6%
Others	6.6%
Total	100%

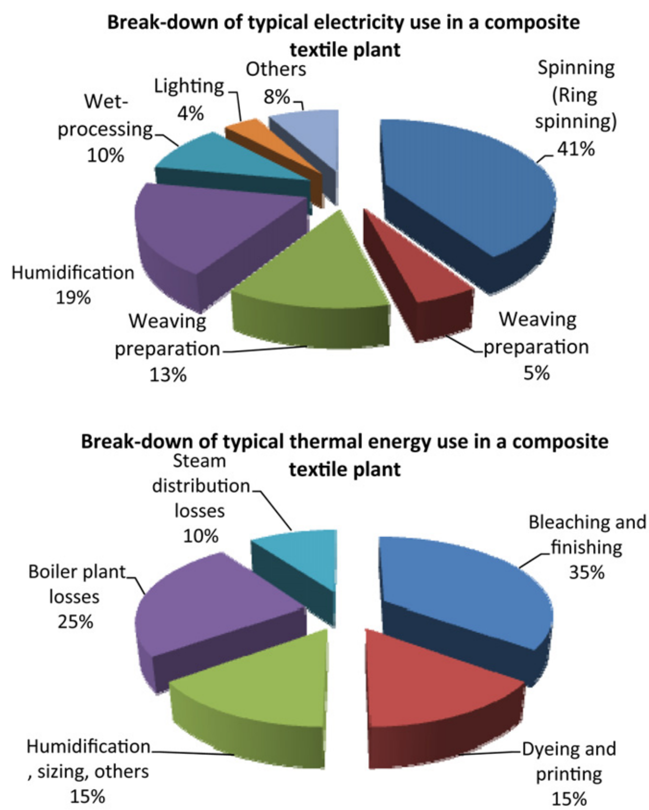

Fig. 8. Breakdown of typical electricity and thermal energy used in a composite textile plant [105].

energy (35%). A significant amount of thermal energy is also lost during steam generation and distribution (35%). These percentages will vary by plant.

5. Energy-efficiency improvement opportunities in the textile industry

This analysis of energy-efficiency improvement opportunities in the textile industry includes both opportunities for retrofit/process optimization as well as the complete replacement of the current machinery with state-of-the-art new technology. However, special attention is paid to retrofit measures since state-of-the-art new technologies have high upfront capital costs, and therefore the energy savings which result from the replacement of current equipment with new equipment alone in many cases may not justify the cost. However, if all the benefits received from the installation of the new technologies, such as water savings, material saving, reduced waste and waste water, reduced redoing, higher product quality, etc. are taken into account, the new technologies are more justifiable economically.

Furthermore, we have tried to present measures for which we could find quantitative values for energy savings and cost. However, in some cases we could not find such quantitative values, yet since some measures are already well-known for their energy-saving value, we decided to include them in the paper despite lacking quantitative metrics of their potential. We believe that the knowledge about the existence of these technologies/measures can help the textile plants engineers to identify available opportunities for energy-efficiency improvements.

Also, it should be noted that the energy saving and cost data provided in this paper are either typical saving/cost or plant/case-specific data. The savings from and cost of the measures can vary depending on various factors such as plant and process-specific factors, the type of fiber, yarn, or fabric, the quality of raw materials, the specifications of the final product as well as raw materials (e.g. fineness of fiber or yarn, width or specific weight of fabric g/m^2, etc.), the plant's geographical location, etc. For instance, for some of the energy-efficiency measures, a significant portion of the cost is the labor cost; thus, the cost of these measures in the developed and developing countries may vary significantly.

5.1. Energy-efficiency technologies and measures in the spun yarn spinning process

Table 5 provides the list of measures/technologies included in this paper for the spun yarn spinning process. The energy efficiency measures are given for five sub-categories for spinning process: preparatory process; ring frame; windings, doubling, and finishing process; air conditioning and humidification system; and general measures for spinning plants. A detailed explanation of each energy efficiency technology/measure given in this paper can be found in [72].

5.2. Energy-efficiency technologies and measures in the weaving process

Weaving machines (looms) account for about 50–60% of total energy consumption in a weaving plant. Humidification, compressor and lighting accounts for the rest of the energy used, depending on the types of the looms and wet insertion techniques [108]. Since a loom is just one machine, there are not many physical retrofits that can be done on existing looms to improve their efficiency. Of course the looms differ in their energy intensity (energy use per unit of product). However, for a given type of the loom, most of the opportunities for energy-efficiency improvements are related to the way the loom is used (productivity), the auxiliary utility (humidification, compressed air system, lighting, etc.), and the maintenance of the looms.

All measures mentioned in Table 5 which improve the efficiency of humidification and compressed air systems used in spinning processes are also to a great extent applicable to weaving plants. In addition to these, the following measures for efficiency improvements of the weaving process are also available opportunities:

29. Loom utilization should be more than 90%. A 10% drop in utilization of loom machines will increase specific energy consumption by 3–4% [108].
30. The electric motor of the loom can be replaced by an energy-efficient motor.
31. The type of weaving machine can significantly influence the energy use per unit of product. Therefore, when buying new looms, the energy efficiency of the loom should be kept in mind. However, it should be noted that some looms can only produce

Table 5
List of energy-efficiency measures and technologies for the spinning process.[a] (*Note*: For the measures that energy saving and cost data are not given, no quantitative data were available.)

No.	Energy-efficiency technologies and measures in spinning plants	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (year)[b]	References
5.1.1	**Preparatory process**					
1	Installation of electronic Roving end-break stop-motion detector instead of pneumatic system		3.2 MWh/year/machine	180/roving machine	<1	[56]
2	High-speed carding machine			100,000/carding machine	<2	[93]
5.1.2	**Ring frame**					
3	Use of energy-efficient spindle oil		3–7% of ring frame energy use			[82]
4	Optimum oil level in the spindle bolsters					[82]
5	Replacement of lighter spindle in place of conventional spindle in Ring frame		23 MWh/year/ring frame	13,500/ring frame	8	[57]
6	Synthetic sandwich tapes for Ring frames		4.4–8 MWh/ring frame/year	540–683/ring frame	1–2	[58,96]
7	Optimization of Ring diameter with respect to yarn count in ring frames		10% of ring frame energy use	1600/ring frame	2	[17]
8	False ceiling in Ring spinning section		8 kWh/year/spindle	0.7/spindle	1.2	[59]
9	Installation of energy-efficient motor in Ring frame		6.3–18.83 MWh/year/motor	1950–2200/motor	2–4	[57,60]
10	Installation of energy-efficient excel fans in place of conventional aluminum fans in the suction of Ring Frame		5.8–40 MWh/year/fan	195–310/fan	<1	[54,57]
11	The use of light weight bobbins in Ring frame		10.8 MWh/year/ring frame	660/ring frame	<1	[58]
12	High-speed Ring spinning frame		10–20% of ring frame energy use			[93]
13	Installation of a soft starter on motor drive of Ring frame		1–5.2 MWh/year/ring frame		2	[11,135]
5.1.3	**Windings, doubling, and finishing process**					
14	Installation of Variable Frequency Drive on Autoconer machine		331.2 MWh/year/plant	19500/plant	<1	[61]
15	Intermittent mode of movement of empty bobbin conveyor in the Autoconer/cone winding machines		49.4 MWh/year/plant	1100/plant	<1	[61]
16	Modified outer pot in Tow-For-One (TFO) machines		4% of TFO energy use			[17,107]
17	Optimization of balloon setting in Two-For-One (TFO) machines					[54]
18	Replacing the Electrical heating system with steam heating system for the yarn polishing machine	Increased 31.7 tons steam/year/machine	19.5 MWh/year/machine	980/humidification plant	<1	[62]
5.1.4	**Air conditioning and humidification system**					
19	Replacement of nozzles with energy-efficient mist nozzles in yarn conditioning room		31 MWh/year/humidification plant	1700/humidification plant	<1	[60]
20	Installation of Variable Frequency Drive (VFD) for washer pump motor in Humidification plant		20 MWh/year/humidification plant	1100/humidification plant	<1	[40,54]
21	Replacement of the existing Aluminum alloy fan impellers with high efficiency F.R.P (Fiberglass Reinforced Plastic) impellers in humidification fans and cooling tower fans		55.5 MWh/year/fan	650/fan	<1	[43]
22	Installation of VFD on Humidification system fan motors for the flow control		18–105 MWh/year/fan	1900–8660/fan	1–2	[43,121]
23	Installation of VFD on Humidification system pumps		35 MWh/year/humidification plant	7100/humidification plant	2.7	[43]

Table 5 (*Continued*)

No.	Energy-efficiency technologies and measures in spinning plants	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (year)[b]	References
24	Energy-efficient control system for humidification system		50 MWh/year/humidification plant	7300–12,200/humidification plant	2–3.5	[81,99]
5.1.5	**General measures for spinning plants**					
25	Energy conservation measures in Overhead Traveling Cleaner (OHTC)		5.3–5.8 MWh/year/OHTC	180–980/OHTC	0.5–2.5	[66]
26	Energy-efficient blower fans for Overhead Traveling Cleaner (OHTC)		2 MWh/year/fan	100/fan	<1	[66]
27	Improving the Power Factor of the plant (Reduction of reactive power)		24.1 MWh/year/plant	3300/plant	1.8	[58]
28	Replacement of Ordinary 'V – Belts' by Cogged 'V – Belts'		1.5 MWh/year/belt	12.2/belt	<1	[58]

[a] The energy savings, costs, and payback periods given in the table are for the specific conditions cited. There are also some ancillary (non-energy) benefits from the implementation of some measures. Read the explanation of each measure in the report [72] to get a complete understanding of the savings and costs.

[b] Wherever the payback period was not provided, but the energy and cost were given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

Table 6
Thermal energy use in dyeing plants (average of Japan) [40].

Item	Share of total thermal energy use	Way to reduce losses[a]
Product heating	16.6%	
Product drying	17.2%	Avoid over-drying
Losses through waste liquor	24.9%	Recovery of waste heat
Heat released from equipment	12.3%	Improved insulation
Exhaust losses	9.3%	Reduction of exhaust gas
Equipment idling losses	3.7%	Stop energy during idling
Evaporation from liquid surface	4.7%	Install a cover
Un-recovered condensate	4.1%	Condensate recovery
Loss during condensate recovery	0.6%	
Others	6.6%	
Total	100%	

[a] This table provides a general example of methods of reducing thermal energy losses. More detail of these methods and the related energy efficiency measures are given below for different process steps.

fabrics with certain specifications and not all looms can produce all types of fabrics. Hence, we cannot give a general suggestion for the type of the loom that should be used; rather, analysis should be done for each specific condition.

32. The quality of warp and weft yarn directly influences the productivity and hence efficiency of the weaving process. Therefore, using yarns with higher quality that may have a higher cost will result in less yarn breakage and stoppage in the weaving process and can eventually be more cost-effective than using cheap, low quality yarns in weaving.

5.3. Energy-efficiency technologies and measures in wet-processing

Table 6 shows a snapshot of the average values for thermal energy use in dyeing plants in Japan. That table provides a good example of the proportion of thermal energy use and losses for each purpose in a dyeing plant, clearly indicating where the greatest energy-efficiency potential lies. Additionally, the table gives useful information about where losses are most significant and therefore which losses should be addressed first. It also presents the general ways of reducing the losses mentioned in the table.

Table 7 provides a list of measures/technologies included in this paper for the wet-processing. The energy efficiency measures are given for five sub-categories for wet-processing plants: preparatory process; dyeing and printing process; drying; finishing process; and general measures for wet-processing. A detailed explanation of each energy efficiency technology/measure given in this paper can be found in [72].

5.4. Energy-efficiency technologies and measures in man-made fiber production

Table 8 provides a list of measures/technologies included in this paper for the man-made fiber production. Detailed explanation of each energy efficiency technology/measure given in this paper can be found in [72].

5.5. Cross-cutting energy-efficiency measures

Table 9 provides a list of cross-cutting energy-efficiency measures/technologies included in [72]. When considering energy-efficiency improvements to a facility's motor systems, a systems approach incorporating pumps, compressors, and fans must be used in order to attain optimal savings and performance. In the following, considerations with respect to energy use and energy saving opportunities for a motor system are presented and in some

Table 7
List of energy-efficiency measures and technologies for the wet-processing.[a,b] (*Note*: For the measures that energy saving and cost data are not given, no quantitative data were available).

No.	Energy-efficiency technologies and measures in wet-processing	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (year)[d]	References
5.3.1	**Preparatory process**					
33	Combine Preparatory Treatments in wet processing	Up to 80% of Preparatory Treatments energy use				[14]
34	Cold-Pad-Batch pretreatment	Up to 38% of pretreatment fuel use	Up to 50% of pretreatment electricity use			[70]
35	Bleach bath recovery system[c]	US$38,500–US$118,400 saving		80,000–246,000	2.1	[14,89]
36	Use of Counter-flow Current for washing	41–62% of washing energy use				[14,40,41,110]
37	Installing Covers on Nips and Tanks in continuous washing machine					[14]
38	Installing automatic valves in continuous washing machine				<0.5	[14]
39	Installing heat recovery equipment in continuous washing machine	5 GJ/ton fabric				[14]
40	Reduce live steam pressure in continuous washing machine					[14]
41	Introducing Point-of-Use water heating in continuous washing machine	Up to 50% of washing energy use				[14]
42	Interlocking the running of exhaust hood fans with water tray movement in the yarn mercerizing machine		12.3 MWh/year/machine		<0.5	[50]
43	Energy saving in cooling blower motor by interlocking it with fabric gas singeing machine's main motor		2.43 MWh/year/machine		<0.5	[45]
44	Energy saving in shearing machine's blower motor by interlocking it with the main motor		2.43 MWh/year/machine		<0.5	[45]
45	Enzymatic removal of residual hydrogen peroxide after bleach	2780 GJ/year/plant				[3,26]
46	Enzymatic scouring					[27]
47	Use of integrated dirt removal/grease recovery loops in wool scouring plant	2 MJ/kg of greasy wool		615,000–1,230,000/system	2–4	[67]
5.3.2	**Dyeing and printing process**					
48	Installation of Variable Frequency Drive on pump motor of Top dyeing machines		26.9 MWh/year/machine	3100/machine	1.5	[63]
49	Heat Insulation of high temperature/high pressure dyeing machines	210–280 GJ/year/plant		9000–13,000/plant	3.8–4.9	[14,62,67,104]

Table 7 (*Continued*)

No.	Energy-efficiency technologies and measures in wet-processing	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (year)[d]	References
50	Automated preparation and dispensing of chemicals in dyeing plants			Chemical Dispensing System: 150,000–890,000; Dye Dissolving and Distribution: 100,000–400,000; Bulk Powder Dissolution and Distribution:76,000–600,000	1.3–6.2; 4–5.7; 3.8–7.5	[21,67]
51	Automated dyestuff preparation in fabric printing plants			23,100–2,308,000/system		[28]
52	Automatic dye machine controllers[c]			57,000–150,000/system	1–5	[28,51,89]
53	Cooling water recovery in batch dyeing machines (Jet, Beam, Package, Hank, Jig and Winches)	1.6–2.1 GJ/ton fabric		143,000–212,000/system	1.3–3.6	[14,28,70,89]
54	Cold-Pad-Batch dyeing system	16.3 GJ/ton of dyed fabric		1215000/system	1.4–3.7	[89]
55	Discontinuous dyeing with airflow dyeing machine	Up to 60% of machine's fuel use		190,500–362,000/machine		[29]
56	Installation of VFD on circulation pumps and color tank stirrers		138 MWh/year/plant	2300/plant	<1	[46]
57	Dyebath Reuse	US$4500 saving/dye machine		24,000–34,000/dye machine		[142]
58	Equipment optimization in winch beck dyeing machine		30% of machine's electricity use			[67]
59	Equipment optimization in jet dyeing machines	1.8–2.4 kg steam/kg fabric	increased 0.07–0.12 kWh/kg fabric	221,000/machine	1.4–3.1	[14,67,89]
60	Single-rope flow dyeing machines	2.5 kg steam/kg fabric	0.16–0.20 kWh/kg fabric		<1	[67]
61	Microwave dyeing equipment	96% reduction compared to beam dyeing	90% reduction compared to beam dyeing	450,000/machine		[40]
62	Reducing the process temperature in wet batch pressure-dyeing machines					[14]
63	Use of steam coil instead of direct steam heating in batch dyeing machines (Winch and Jigger)	4580 GJ/year/plant		165,500/plant		[11]
64	Reducing the process time in wet batch pressure-dyeing machines					[14]
65	Installation of covers or hoods in atmospheric wet batch machines					[14]
66	Careful control of temperature in atmospheric wet batch machines	27–91 kg steam/h				[14]

Table 7 (*Continued*)

No.	Energy-efficiency technologies and measures in wet-processing	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (year)[d]	References
67	Jiggers with a variable liquor ratio	26% reduction compared to conventional jigger				[30]
68	Heat recovery of hot waste water in Autoclave	554 MJ/batch product				[41]
69	Insulation of un-insulated surface of Autoclave	15 MJ/batch product				[41]
70	Reducing the need for re-processing in dyeing	10–12%				[14]
71	Recover heat from hot rinse water	1.4–7.5 GJ/ton fabric rinsed		44,000–95,000	<0.5	[70]
72	Reuse of washing and rinsing water					[31]
73	Reduce rinse water temperature	10%		0		[124]
5.3.3	**Drying** Energy-efficiency improvement in Cylinder dryer					
74	Introduce Mechanical Pre-drying					[14]
75	Selection of Hybrid Systems	25–40%				[14]
76	Recover Condensate and Flash Steam					[14]
77	End Panel Insulation					[14]
78	Select Processes for their Low Water Add-on Characteristics					[14]
79	Avoid Intermediate Drying					[14]
80	Avoid Overdrying					[14,41]
81	Reduce Idling Times and Use Multiple Fabric Drying					[14]
82	Operate Cylinders at Higher Steam Pressures					[14]
83	Maintenance of the dryer					[14]
84	The use of radio frequency dryer for drying acrylic yarn	US$45,000 saving/plant		200,000/plant		[11]
85	The use of Low Pressure Microwave drying machine for bobbin drying instead of dry-steam heater		107 kWh/ton yarn	500,000/plant	<3	[2]
86	High-frequency reduced-pressure dryer for bobbin drying after dyeing process		200 kWh/ton product	500,000/machine		[40]
5.3.4	**Finishing process** Energy-efficiency improvement in Stenters					
87	Conversion of Thermic Fluid heating system to Direct Gas Firing system in Stenters and dryers	11,000 GJ/year/plant	120 MWh/year/plant	50,000/plant	1	[32]
88	Introduce Mechanical De-watering or Contact Drying Before Stenter	13–50% of stenter energy use				[5,33,67]
89	Avoid Overdrying					[14]
90	Close Exhaust Streams during Idling					[67]
91	Drying at Higher Temperatures					[14]
92	Close and Seal Side Panels					[14]

Table 7 (*Continued*)

No.	Energy-efficiency technologies and measures in wet-processing	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (year)[d]	References
93	Proper Insulation	20% of stenter energy use				[67]
94	Optimize Exhaust Humidity	20–80% of stenter energy use				[34,41]
95	Install Heat Recovery Equipment	30% of stenter energy use		77,000–460,000/system	1.5–6.6	[9,14,35,67]
96	Efficient burner technology in Direct Gas Fired systems					[67]
97	The Use of Sensors and Control Systems in Stenter	22% of stenter fuel use	11% of stenter electricity use	Moisture humidity controllers: 20,000–220,000; dwell time controls: 80,000–400,000	Moisture humidity controllers: 1.5–5; dwell time controls: 4–6.7	[21,36,98]
5.3.5	**General energy-efficiency measures for wet-processing**					
98	Automatic steam control valves in Desizing, Dyeing, and Finishing	3250 GJ/year/plant		5100/plant		[64]
99	The recovery of condensate in wet processing plants	1.3–2 GJ/ton fabric		1000–16,000	1–6	[21,70,104]
100	Heat recovery from the air compressors for use in drying woven nylon nets	7560 GJ/year/plant		8500/year/plant		[15]
101	Utilization of heat exchanger for heat recovery from wet-processes wastewater	1.1–1.4 GJ/ton finished fabric		328,820/system		[41,85,100,104]

[a] Typical energy requirements for textile wet-processes, by product form, machine type and process are given in Table 3.

[b] The energy savings, costs, and payback periods given in the table are for the specific conditions. There are also some ancillary (non-energy) benefits from the implementation of some measures. Please read the explanation of each measure in [72] to get a complete understanding of the savings and costs.

[c] Savings of this measure are the net annual operating savings (average per plant) which includes energy and non-energy savings.

[d] Wherever the payback period was not given while the energy and cost are given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

Table 8
List of energy-efficiency measures and technologies for the man-made fiber production.[a] (*Note*: For the measures that energy saving and cost data are not given, no quantitative data were available.)

No.	Energy-efficiency technologies and measures in man-made fiber production	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (years)[b]	References
102	Installation of Variable Frequency Drive (VFD) on hot air fans in after treatment dryer in Viscose Filament production		105 MWh/year/dryer	11,000/dryer	1.3	[19,53]
103	The use of light weight carbon reinforced spinning pot in place of steel reinforced pot		9.6 MWh/spinning machine/year	680/machine	<1	[114]
104	Installation of Variable Frequency Drives in fresh air fans of humidification system in man-made fiber spinning plants		32.8 MWh/fan/year	5600/fan	2.3	[65]
105	Installation of Variable Frequency drives on motors of dissolvers		49.5 MWh/agitator/year	9500/agitator	2.6	[53,65]
106	Adoption of pressure control system with VFD on washing pumps in After Treatment process		40.4 MWh/pump/year	930/pump	<1	[55]
107	Installation of lead compartment plates between pots of spinning machines		7 MWh/machine/year		<0.5	[47]
108	Energy-efficient High Pressure steam-based Vacuum Ejectors in place of Low Pressure steam-based Vacuum Ejectors for Viscose Deaeration	3800 GJ/year/plant		29,000/plant		[44]
109	The use of heat exchanger in dryer in Viscose filament production	1 GJ/h of dryer operation		66,700/system		[6]
110	Optimization of balloon setting in TFO machines		205 MWh/year/plant			[71]
111	Solution spinning high-speed yarn manufacturing equipment (for filament other than urethane polymer)		500 MWh/machine (16 spin-dles)/year	200,000/machine	5.3	[93]
112	High-speed multiple thread-line yarn manufacturing equipment for producing nylon and polyester filament		55%	320,000/machine		[93]
113	Reduction in height of spinning halls of man-made fiber production by installation of false ceiling		788 MWh/year/plant	190,000/plant	3.2	[55]
114	Improving motor efficiency in draw false-twist texturing machines		73 MWh/year/machine	80,000/machine	14.6	[93]

[a] The energy savings, costs, and payback periods given in the table are for the specific conditions. There are also some ancillary (non-energy) benefits from the implementation of some measures. Please read the explanation of each measure in [72] to get the complete understanding of the savings and costs.
[b] Wherever the payback period was not given while the energy and cost are given, the payback period is calculated assuming the price of electricity of US$75/MWh (US$0.075/kWh).

Table 9
List of cross-cutting energy-efficiency measures and technologies.[a] (*Note*: For the measures that energy saving and cost data are not given, no quantitative data were available.)

No.	Cross-cutting energy-efficiency technologies and measures	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (years)	References
5.5.1	**Electrical demand control**					
115	Electrical demand control					[91,103]
5.5.2	**Energy-efficiency improvement opportunities in *electric motors***					
116	Motor management plan					[24]
117	Maintenance		2–30% of motor system energy use			[4,42]
118	Energy-efficient motors					[23]
119	Rewinding of motors					[24,37,38]
120	Proper motor sizing					[139]
121	Adjustable speed drives		7–60%		<3	[72,137]
122	Power factor correction					[115]
123	Minimizing voltage unbalances				<3	[123,130]
5.5.3	**Energy-efficiency improvement opportunities in *compressed air* systems**					
124	Reduction of demand					[139]
125	Maintenance					[139]
126	Monitoring					[12]
127	Reduction of leaks (in pipes and equipment)		Up to 20% of compressed air system energy use			[80,102]
128	Electronic condensate drain traps (ECDTs)					[139]
129	Reduction of the inlet air temperature		each 3 °C reduction will save 1% compressor energy use		<5	[12,97]
130	Maximizing allowable pressure dew point at air intake					[80]
131	Optimizing the compressor to match its load					[16]
132	Proper pipe sizing		Up to 3% of compressed air system energy use			[102]
133	Heat recovery		Up to 20% of compressed air system energy use		<1	[16,97,102,116]
134	Adjustable speed drives (ASDs)		Up to 15% of compressed air system energy use			[74,102]
5.5.4	**Energy-efficiency improvement opportunities in *pumping* systems**					
135	Maintenance		2–7% of pumping electricity use		<1	[128,141]
136	Monitoring					[76]
137	Controls					[139]
138	Reduction of demand		10–20% of pumping electricity use			[39]
139	More efficient pumps		2–10% of pumping electricity use			[78,92,112]
140	Proper pump sizing		15–25% of pumping electricity use		<1	[39,128]
141	Multiple pumps for varying loads		10–50% of pumping electricity use			[39]
142	Impeller trimming (or shaving sheaves)		Up to 75% of pumping electricity use			[129,141]
143	Adjustable speed drives (ASDs)		20–50% of pumping electricity use			[7,141]
144	Avoiding throttling valves					[76,113]
145	Proper pipe sizing					[129]
146	Replacement of belt drives		Up to 8% of pumping electricity use		<0.5	[109]
147	Precision castings, surface coatings or polishing					[139]
148	Improvement of sealing					[79]
5.5.5	**Energy-efficiency improvement opportunities in *fan* systems**					
149	Minimizing pressure					[87]
150	Control density					[87]
151	Fan efficiency					[87]
152	Proper fan sizing					[141]
153	Adjustable speed drives (ASDs)		14–49% of fan system electricity use			[141]
154	High efficiency belts (cogged belts)		2% of fan system electricity use		1–3	[141]

Table 9 (*Continued*)

No.	Cross-cutting energy-efficiency technologies and measures	Fuel saving	Electricity saving	Capital cost (US$)	Payback period (years)	References
5.5.6	**Energy-efficiency improvement opportunities in *lighting* system**					
155	Lighting controls				<2	[139]
156	Replace T-12 tubes by T-8 tubes		114 MWh/year/1196 light bulbs	26,800 for 1196 light bulbs		[65,105]
157	Replace Mercury lights by Metal Halide or High Pressure Sodium lights		50–60%/bulb			[139]
158	Replace Metal Halide (HID) with High-Intensity Fluorescent lights		50%/bulb	185/fixture		[139]
159	Replace Magnetic Ballasts with Electronic Ballasts		936 kWh/ballast/year	8/ballast		[48,139]
160	Optimization of plant lighting (Lux optimization) in production and non-production departments		31–182 MWh/year			[49,54,55]
161	Optimum use of natural sunlight					[54,64]
5.5.7	**Energy-efficiency improvement opportunities in *steam* systems**					
162	Demand Matching				<2	[123,131]
163	Boiler allocation control					[13]
164	Flue shut-off dampers					[13]
165	Maintenance	Up to 10% of boiler energy use			<0.5	[123,127]
166	Insulation improvement	6–26% of boiler energy use				[10]
167	Reduce Fouling					[20,131]
168	Optimization of boiler blowdown rate				1–3	[123,131]
169	Reduction of flue gas quantities					[139]
170	Reduction of excess air				<1	[131]
171	Flue gas monitoring				<1	[123]
172	Preheating boiler feed water with heat from flue gas (economizer)	5–10% of boiler energy use			<2	[131]
173	Recovery of heat from boiler blowdown				<2	[13,123]
174	Recovery of condensate				1	[123,131]
175	Combined Heat and Power (CHP)					[94]
176	Shutting off excess distribution lines					[139]
177	Proper pipe sizing					[134]
178	Insulation related measures				1.1	[123,131]
179	Checking and monitoring steam traps	Up to 10% of boiler energy use			<0.5	[8,83,123,131]
180	Thermostatic steam traps					[1]
181	Shutting of steam traps				<0.5	[123]
182	Reduction of distribution pipe leaks				<0.5	[123]
183	Recovery of flash steam					[84,131]
184	Prescreen coal	1.8 GJ/ton finished fabric		35,000/system	<0.5	[70]

[a] The energy savings, costs, and payback periods given in the table are for the specific conditions. There are also some ancillary (non-energy) benefits from the implementation of some measures. Please read the explanation of each measure in [72] to get a complete understanding of the savings and costs.

cases illustrated by case studies. Pumping, fan and compressed air systems are discussed in addition to the electric motors. Steam systems are often found in textile plants and can account for a significant amount of end-use energy consumption. Improving boiler efficiency and capturing excess heat can result in significant energy savings and improved production. Common performance improvement opportunities for the generation and distribution of industrial steam systems are given bellow. Detailed explanation of each energy efficiency technology/measure given in this paper can be found at [73,139].[5]

6. Conclusions

Energy is one of the main cost factors in the textile industry. Especially in times of high energy price volatility, improving energy efficiency should be one of the main concerns of textile plants. There are various energy-efficiency opportunities in textile plants, many of which are cost-effective. However, even cost-effective options often are not implemented in textile plants due mainly to limited information on how to implement energy-efficiency measures, especially given the fact that the majority of textile plants are categorized as small and medium enterprises (SMEs). These plants in particular have limited resources to acquire this information. Know-how regarding energy-efficiency technologies and practices should, therefore, be prepared and disseminated to textile plants.

This paper is a review of energy use and energy-efficiency technologies and measures applicable to the textile industry. The paper includes case studies from textile plants from around the world with energy savings and cost information when available. For some measures the paper provides a range of savings and payback periods found under varying conditions. At all times, the reader must bear in mind that the values presented in this paper are offered as guidelines. Actual cost and energy savings for the measures will vary, depending on plant configuration and size, plant location, plant operating characteristics, production and product characteristics, the local supply of raw materials and energy, and several other factors. Therefore, for all energy-efficiency measures presented in this paper, individual plants should pursue further research on the economics of the measures, as well as on the applicability of different measures to their own unique production practices, in order to assess the feasibility of measure implementation.

[5] Cross-cutting energy efficiency measures are mostly obtained from [139]. However, the original sources of each individual measure are also provided in Table 9 for further information.

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